



Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at <http://about.jstor.org/participate-jstor/individuals/early-journal-content>.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

CAUSES OF MAGMATIC DIFFERENTIATION.

IN petrographical literature in recent years attention has repeatedly been drawn to the fact, that igneous rocks, which are closely connected geographically and in age, are also chemically related to one another, showing a certain "consanguinity"—to use Iddings'¹ very fitting expression—a relationship which makes them form a distinct "petrographical province" (Judd) when compared with igneous rocks of other parts of the world. The cause of this relationship has been sought in the supposition, that all the different rocks of the "petrographical province" come from the differentiation of one common magma, originally homogeneous.

As to the manner in which the differentiation took place, opinions are divided. We may suppose that it took place during the consolidation of the magma; in this way, a part of the minerals crystallized out, then were mechanically accumulated and finally reliquified. The differentiation of the original magma into partial magmas could take place in this way, but, as far as I can see, only on a small scale. A silicate magma during its period of crystallization is certainly too viscous to permit of any considerable diffusion. For example, in the reproduction of rocks after the method of Fouqué and Lévy, in which process a glass is first made having the desired composition, this glass may be completely devitrified (fused), while it remains so viscous that pieces of it neither change form nor adhere to one another.

Another theory, namely, that the differentiation has taken place in the magma while quite fluid, possesses greater probability and therefore more adherents. But concerning the details of the method opinions differ. While certain petrographers apply the

¹ "Origin of Igneous Rocks." Bull. Phil. Soc. of Washington, 12. 89-214. (1892). This paper contains an extensive bibliography of this subject, to which the reader is referred.

laws of dilute solutions to explain the differentiation of the molten silicate magmas, others look upon the separation of the original magma into partial magmas as evidence of the incapacity of the chemical compounds, constituting the original magma, to dissolve one another completely at all states of temperature and pressure. This latter theory is not as yet very much developed, but has been considered by Durocher and Rosenbusch, whereas the first theory, which consists essentially in the application of what Teall has termed "Soret's principle," has been used by several authors, in greatest detail by Vogt.

The principle known in petrographical literature as "Soret's principle" can be correctly formulated thus: "If in the same dilute solution, the temperature is different in different places, the concentration varies also and in such a manner, that, when equilibrium is established in every point, it is universally proportional to the absolute temperature"—for, the osmotic pressure is proportional to the absolute temperature, and if the pressure is augmented in one place, part of the molecules must be driven over to the place with less osmotic pressure, in order to maintain the equilibrium. Here, as in the other applications of the laws of gases to solutions, it must be remembered that these laws apply rigidly only to very dilute solutions; concerning the behavior of concentrated solutions we know very little, and especially with reference to "Soret's principle." Further, if two or more substances are contained in the solution a difference of temperature could not change the *relative* concentration any more than it could change the composition of a gas-mixture.¹ The only thing that is altered is the proportion between the solvent and the substance dissolved.

Consequently such definitions of "Soret's principle" as "The compound or compounds with which the solution is nearly saturated tend to accumulate in the colder parts,"² and "The most

¹ In very concentrated solutions it might happen that the osmotic pressure is a different function of the temperature for the different substances in solution, and then the relative concentration would be changed.

² TEALL: "British Petrography," 394. (London, 1888). ZIRKEL: "Lehrbuch der Petrographie," Vol. I., 779. (Leipzig, 1893).

difficultly soluble compounds diffuse towards the plane of cooling"¹ are misconceptions. It is the proportion between the solvent and the dissolved substance which is changed and this is all—so far as we know at present. Consequently, in order that one may use "Soret's principle" for the purposes of theoretical petrography it is quite necessary to have the question settled: what is "the solvent" and what "the thing dissolved?"

Vogt² avoids this difficulty in the following way. He says: "Owing to chemical action certain 'liquid-molecules' are individualized, which are preliminarily kept dissolved in the resting magma, and which only by a subsequent lowering of temperature, or pressure, are separated in the solid condition. The minerals which crystallize first at every stage may consequently be considered originally 'dissolved' in the remaining 'mother-liquor.'" Here we find at first the supposition, that certain compounds are "individualized"³ in preference to others, and consequently the latter as not "individualized" form a sort of chaos. But this remainder must certainly consist also of chemical compounds. The author has perhaps thought that they should be dissociated, but it must be remembered that the free ions cannot diffuse independently of one another.

In the latter part of the quotation it is stated, that the substance which crystallizes out first when temperature sinks is to be considered as dissolved in the solvent, which crystallizes at a still lower temperature. But, in general, it is the solvent which crystallizes out first when the temperature falls, and this crystallization goes on until the "eutectic proportion" (Guthrie) is reached, when both the substance dissolved and the solvent crystallize simultaneously until the whole is solidified. If Vogt's reasoning is correct, the more a dilute solution of nitre is diluted with water, so much the more should the water be regarded as the substance dissolved.

¹ "Die am schwersten löslichen Verbindungen diffundiren nach der Abkühlungsfläche hin." BRÖGGER: *Zeitschr. f. Krystallographie* 16, 85. (1890).

² *Geologiska Föreningens Förhandlingar* 13. 526. (Stockholm, 1891).

³ Or "constituted" in the German edition, *Zeitschr. f. prakt. Geol.*, 1893, 273.

Thus I have tried to show, that "Soret's principle" cannot be applied to magmas, and consequently, if magmatic differentiation were a process of molecular diffusion it could not be explained. And it seems to me to be going too far to apply the laws of dilute solutions to magmas before having attempted to consider them simply as mixtures of liquids.

As an illustration of the conduct of two liquids when mixed, let us take aniline and water. If they are mixed at ordinary temperature, when equilibrium is established two layers are formed, one containing 1 per cent. of aniline and 99 water, the other 98 aniline and 2 water.¹ But if they are mixed at 100° the two layers formed will contain 4 aniline and 96 water, and 91 aniline and 9 water; at 150° the proportions are 14 aniline and 86 water, and 76 aniline and 24 water; at 160° they are 25 aniline, 75 water, and 68 aniline, 32 water, and at 166° the two layers should have the same composition, being consequently identical. Therefore, *above* 166° aniline and water mix in all proportions, but *below* this temperature the reciprocal dissolving capacity is limited and generally a separation into two layers takes place, the composition of which is a function of the temperature.

This seems to be common for all liquid-mixtures where no chemical action takes place. For all such mixtures there exists a temperature, above which they mix in all proportions. It is true that this temperature is known only for a few combinations of liquids, but it must be regarded as certain that it exists, and if not below then at the critical temperature, because here the capacity of mixing in all proportions is a general property of the gases.

On the other hand, there are certain fluids, which at ordinary temperature dissolve one another without limit, and for these the temperature below which the dissolving capacity is limited is yet to be determined, but in some cases this may not be reached before the transition into the solid form takes place. For us the principal question now is, can we assume that all the chemical

¹The numbers given are obtained by interpolation in the curve of Alexejew in WIEDEMANN'S *Annalen* 28, table 3. (1886).

compounds forming the original rock magma are completely soluble in one another? I think not.

We are told by Vogt¹ that silicates can be melted together in all proportions. This may be true, but it does not prove that this mixture would not separate into layers of different composition, or at least become heterogeneous, if it were kept molten for a sufficient time. The viscosity of molten glasses is very great and consequently the separation must take time. Still evidences of such separation—or *liquation* as we may call it, following Durocher—in the manufacture of glass are not wanting. It is well known to be very difficult to produce large pieces of homogeneous glass, for example for optical purposes. According to Wagner's *Handbuch der chemischen Technologie*² this comes from the fact, "either that the individual compounds formed during the melting process have not dissolved one another or that they have separated from the mixture by a lowering of the temperature"; and further, "One will seldom find large pieces of glass, which are completely free from this fault."³ But it is not necessary to leave the field of geology in order to decide the question whether magmatic differentiation is a diffusion, or a liquation, process. Let us select some examples of differentiation, and examine them in the light of both theories. I have chosen two, one on a small scale, the basic inclusions, and one on a large scale, the great petrographical province of Iceland.

By diffusion, according to "Soret's principle," the basic inclusions could never be thought to have been formed in situ or approximately so—for, between them and the surrounding magma there would be no difference in temperature, or at least no difference sufficient to alter the osmotic pressure, which is proportional to the absolute temperature, or enough to produce

¹ *Zeitschr. f. prakt. Geol.*, 1893, 272.

² 13th edition, 720. (Leipzig, 1889).

³ "Entweder die einzelnen beim Schmelzprocesse entstandenen Verbindungen sich gegenseitig nicht aufgelöst, oder bei einem Nachlassen der Temperatur aus einem Gemenge sich abgeschieden haben"; and further, "Man wird selten grössere Stücke von Glas finden, welche von diesem Fehler vollkommen frei wären."

so radical a change in chemical composition. These inclusions must, by this theory, be considered to be fragments of older rocks, formed in this way. Still basic inclusions may be supposed to have been formed by mechanical agglomeration, and no doubt this has often been the case. But, in opposition to both these theories, it is in many cases evident that the inclusions were *soft*, and then the simplest view is that they were drops, or portions, of a partial magma, which at the temperature, existing immediately before crystallization, could no longer be held in solution by the principal magma, but separated out,

The great petrographical province of Iceland is characterized principally by enormous eruptions of plagioclase-basalts and exceedingly subordinate eruptions of rhyolites, which, however, are very numerous. No other eruptive rocks are known from Iceland up to this time.¹ If we considered the differentiation of the primary magma, which here was very basic, as a diffusion-phenomenon, according to "Soret's principle," it would be incomprehensible why the differentiation never stopped with the production of an intermediate magma, and, moreover, this theory would demand that every little rhyolite-magma previous to the eruptions would have been surrounded by a broad zone, showing all transitions to the basaltic magma. In both cases these intermediate magmas should have been erupted at some time, but, as already mentioned, we know a hundred eruptions of rhyolite but not a single one of andesitic rocks. It therefore seems more probable that these intermediate magmas never existed in the petrographical province of Iceland, but that the acid partial magmas were separated out directly from the basic original magma, which by lowering temperature lost its homogeneity. The conditions of temperature and pressure being different in different places these acid partial magmas also became somewhat different, but may all be classified as soda-rhyolites. The chemical compounds, which constitute the silicate magmas—and which are not necessarily identical with the rock-forming

¹ Refer to H. BÄCKSTRÖM: "Beiträge zur Kenntniss der isländischen Liparite" in Geol. Fören. Förh. 13, 667. (Stockholm, 1891).

minerals—are naturally more than two, and therefore the liquation must become very complicated, being not only a function of temperature but also dependent on the original proportions. Therefore, in other places, where the original magma had another composition, relatively stable andesitic magmas might be formed, but this was evidently not the case in Iceland.

Liquation is no doubt also a function of the pressure, but experimental data are wanting. Still it may be considered as probable that, if liquation would augment the volume of the magma, then pressure would act the same as increase in temperature, and inversely. The first is most frequently the case with liquid-mixtures.

The purpose of this communication is to give to liquation and not to diffusion its place as the working hypothesis, upon which the theory of differentiation is to be constructed. How far this theory may differ from the approximation to it, given by Rosenbusch in his "Kern"-theory, the future will show.

In conclusion, I wish to express my best thanks to my friend and colleague Dr. S. Arrhenius for much valuable information furnished me in numerous discussions on this and other subjects which lie on the border between petrology and physical chemistry.

HELGE BÄCKSTRÖM.